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AERODYNAMIC CHARACTERISTICS OF BASIC AND MODIFIED ARAPAHO "C" TEST VEHICLE CONFIGURATIONS AT MACH NUMBERS FROM 2.5 TO 5

A. W. Myers

ARO, Inc.

December 1966

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FOREWORD

The work reported herein was done at the request of the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), for the Goodyear Aerospace Corporation, Akron, Ohio, under Program Element 62405364, Project 6065.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from June 9 to 13, 1966, under ARO Project No. VT0626, and the manuscript was submitted for publication on October 20, 1966.

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This technical report has been reviewed and is approved.

James N. McCready
Major, USAF
AF Representative, VKF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility on 0.182-scale models of basic and modified configurations of the Arapaho "C" test vehicle. Static stability and drag characteristics data were obtained at Mach numbers from 2.5 to 5 at angles of attack from -5 to 15 deg. Reynolds number, based on the basic Arapaho "C" model length of 15.56 in., ranged from 0.59×10^6 to 7.96×10^6. Selected results are presented showing the effects of Mach number and Reynolds number on the vehicle static stability and drag characteristics.

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NOMENCLATURE

A	Reference area (cross-sectional area of model centerbody), 3.142 in.^{2}
A_b	Base area (see Fig. 1)
C_A	Forebody axial-force coefficient, $C_{A_t} - C_{A_b}$
C_{A_b}	Base axial-force coefficient, $(p_\infty - p_b)A_b/q_\infty A$
C_{A_t}	Total axial-force coefficient, total axial force/$q_\infty A$
C_ℓ	Rolling-moment coefficient, rolling moment/$q_\infty Ad$
C_m	Pitching-moment coefficient, pitching moment/$q_\infty Ad$
C_{m_α}	Initial slope of pitching-moment curve, per deg
C_N	Normal-force coefficient, normal force/$q_\infty A$
C_{N_α}	Initial slope of normal-force curve, per deg
C_n	Yawing-moment coefficient, yawing moment/$q_\infty Ad$
C_Y	Side-force coefficient, side force/$q_\infty A$
d	Reference length (centerbody diameter), 2.000 in.
M_∞	Free-stream Mach number
p_b	Base pressure, psia
p_o	Stilling chamber pressure, psia
p_∞	Free-stream static pressure, psia
q_∞	Free-stream dynamic pressure, psia
Re_d	Reynolds number based on model diameter
T_o	Tunnel stilling chamber temperature, °F
α	Angle of attack, deg
ϕ	Model roll attitude, deg

SECTION I
INTRODUCTION

Tests were conducted in the 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) of the von Kármán Gas Dynamics Facility (VKF), AEDC, to determine the static stability and drag characteristics of basic and modified configurations of the Arapaho "C", a vehicle used primarily as a forebody for testing supersonic decelerators. The tests were made in support of the EUREKA (Establishment of an Unsymmetrical Wake Test Capability for Aerodynamic Decelerators) program. Later tests in this program include flow surveys in the wake and parachute deployments behind strut-mounted models of these Arapaho configurations.

Data were obtained at Mach numbers 2.5, 3, 4, and 5 at Reynolds numbers based on model diameter which ranged from 0.072×10^6 to 1.026×10^6, and at angles of attack from -5 to 15 deg. An unsymmetrical flare configuration was tested at roll attitudes of 0, 22.5, 45, and 90 deg. A summary of the test conditions is presented in Table I.

Selected typical results are presented showing the effects of Mach number and Reynolds number on the vehicle static stability and drag characteristics.

SECTION II
APPARATUS

2.1 WIND TUNNEL

Tunnel A is a continuous, closed-circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum operating pressures are about one-tenth of the maximum at each Mach number. A description of the tunnel and airflow calibration information may be found in the Test Facilities Handbook.*

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*Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.

2.2 MODELS

The 0.182-scale model of the basic Arapaho "C" consists of a cylindrical centerbody with a symmetrical flare afterbody and a probe nose. Two variations in the basic configuration were obtained by replacing the probe nose with a blunted nose cone (configuration 2), and by adding an elliptical flare afterbody as well as the nose cone (configuration 3). Details of the three configurations are shown in Fig. 1, and a photograph of configuration 3 installed in the tunnel is shown in Fig. 2.

2.3 INSTRUMENTATION

Model force measurements were made with a six-component, moment-type, strain-gage balance supplied and calibrated by VKF. Before the test, loadings in a single plane and combined static loadings were applied to the balance which simulated the range of model loadings anticipated for the test. The range of uncertainties listed below corresponds to the difference between the applied loads and the values calculated with the balance equations used in the final data reduction. The minimum uncertainties given are for loads up to about 10 percent of the maximum applied and are for loadings on the particular component only (no combined loading interaction effects). The maximum uncertainties are for combined loadings.

Balance Component	Design Load	Range of Static Loadings	Range of Uncertainties
Normal force, lb	150	±2 to ±60	±0.03 to ±0.12
Pitching moment, in.-lb	690	±10 to ±150	±0.20 to ±0.60
Side force, lb	75	±2 to ±39	±0.03 to ±0.18
Yawing moment, in.-lb	345	±5 to ±80	±0.20 to ±0.90
Rolling moment, in.-lb	60	±24 to ±48	±0.05 to ±0.10
Axial force, lb	75	5 to 25	±0.07 to ±0.12

Model base pressures were measured with 1-, 5-, and 15-psid transducers, referenced to a near vacuum, which are considered accurate to within 0.30 percent of the transducer capacity.

From calibration results, the maximum variation of tunnel centerline Mach number is about ±0.5 percent, and the angle-of-attack setting is considered accurate to within ±0.1 deg.

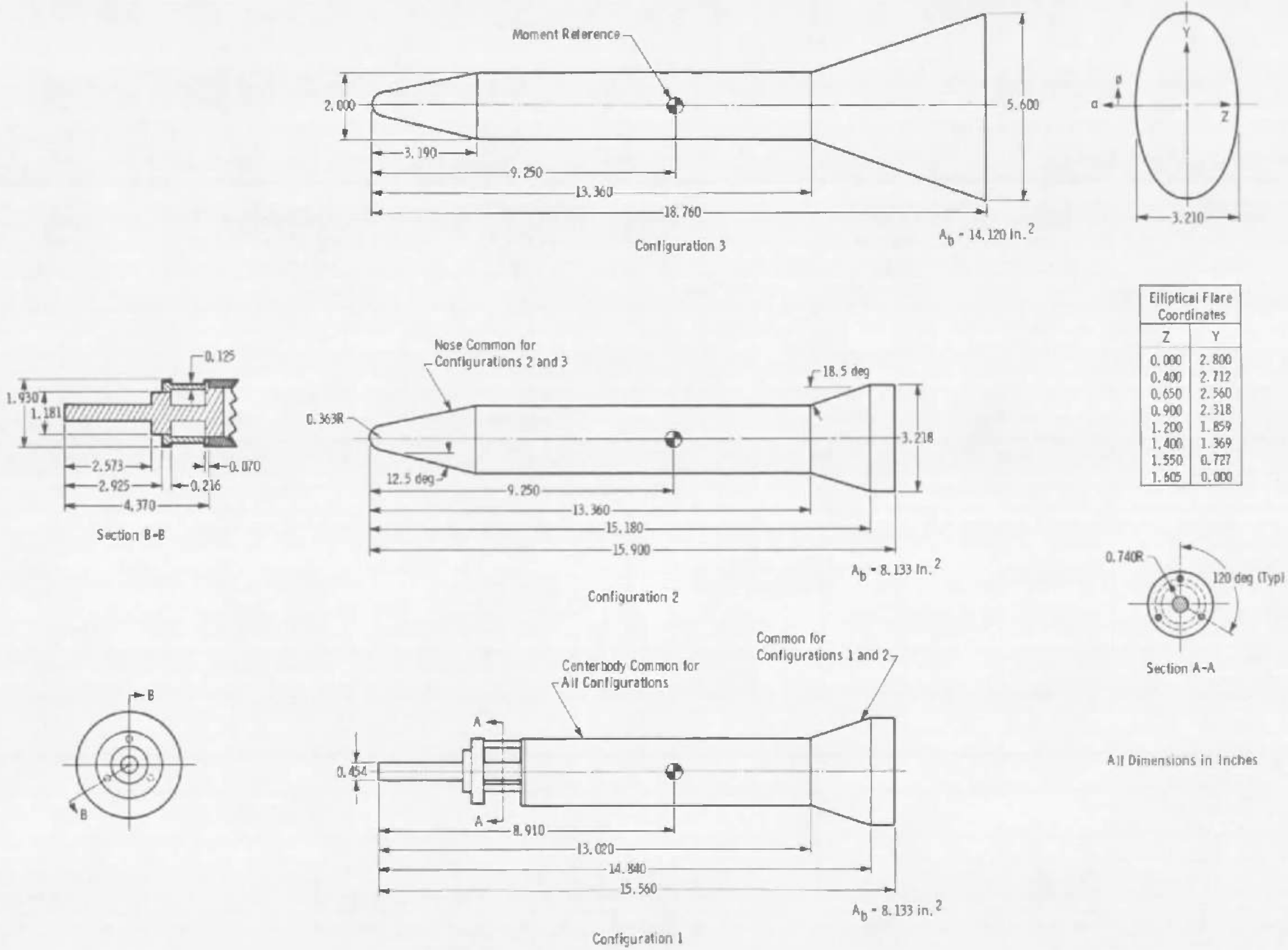
SECTION III
RESULTS AND DISCUSSION

Normal-force, axial-force, and pitching-moment coefficients for the three configurations are shown plotted against angle of attack in Fig. 3. Data are presented for $M_\infty = 2.5$ and 5 for the minimum and maximum Reynolds number condition. For the selected moment reference location, configurations 1 and 3 were statically stable at both Mach numbers, whereas configuration 2 was statically unstable at $M_\infty = 2.5$ for the maximum Reynolds number and stable for the minimum Reynolds number condition for a limited angle-of-attack range. The curves of Fig. 4 show that configurations 1 and 3 were also stable at the intermediate Mach numbers whereas configuration 2 becomes stable for the high Reynolds number, between Mach numbers 3 and 4. This figure also shows a notable decrease in axial force with Mach number increase for all configurations, and further, that although C_{N_α} for configuration 2 increased markedly with Mach number for $M_\infty > 3$, C_{N_α} for configurations 1 and 3 was essentially constant with Mach number.

Shadowgraph pictures of configuration 2, presented in Fig. 5, show the separated flow regions ahead of the flare at Mach numbers 2.5 and 5. At $M_\infty = 2.5$, the flow is clearly attached at the maximum Reynolds number condition, but separation is evident at the lower Reynolds number ($Re_d = 0.56 \times 10^6$). At $M_\infty = 5$, the flow is separated over most of the body, even at the maximum Reynolds number. The Reynolds number effects on the stability of configuration 2 at $M_\infty = 2.5$, noted earlier in Fig. 3, are clearly a result of the flow separation at the minimum Reynolds number. Figure 6 shows that the axial force at zero angle of attack for configuration 2 is also strongly dependent on Reynolds number at all Mach numbers tested except at $M_\infty = 5$, where, as mentioned previously, the flow is separated over most of the body.

The static force characteristics of the elliptical flare configuration 3, when pitched for roll attitudes of 0, 22.5, 45, and 90 deg, are shown in Fig. 7 for Mach numbers 2.5 and 5. The data show that the effects of model roll attitude decrease with Mach number increase, and that at $M_\infty = 5$, vehicle static longitudinal stability differs only slightly for all model roll attitudes. This result is attributed to the large regions of flow separation which essentially blank out the flare contribution to vehicle stability. Axial force showed little or no variation with roll attitude and is not presented. It should be noted here that because of small asymmetries in the large elliptical flare of this configuration, the intercept of the force and moment curves is not always zero at $\alpha = 0$. This can be seen also in Fig. 3 for this model.

APPENDIX I
ILLUSTRATIONS



Elliptical Flare Coordinates	
Z	Y
0.000	2.800
0.400	2.712
0.650	2.560
0.900	2.318
1.200	1.859
1.400	1.369
1.550	0.727
1.605	0.000

Fig. 1 Model Details

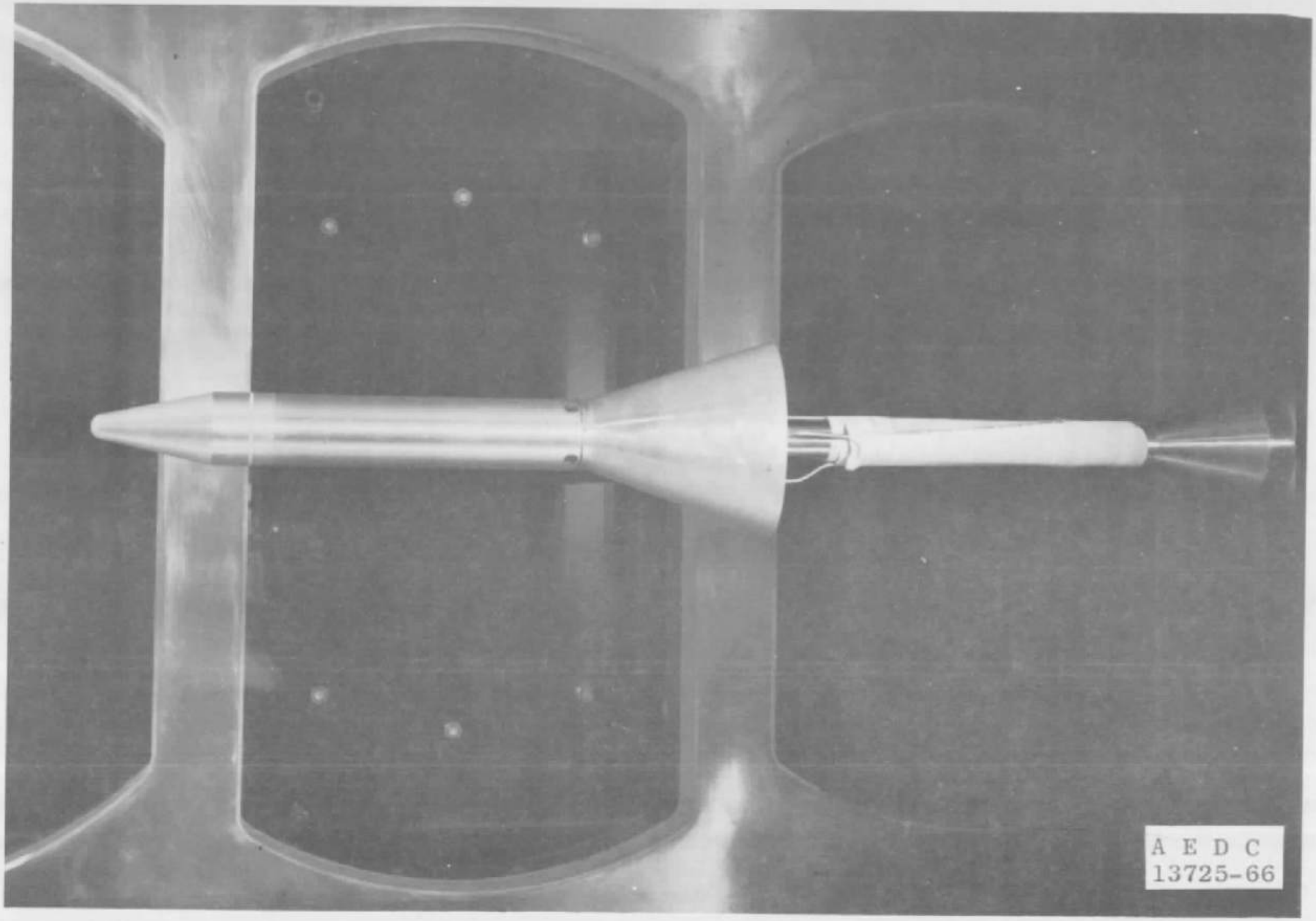
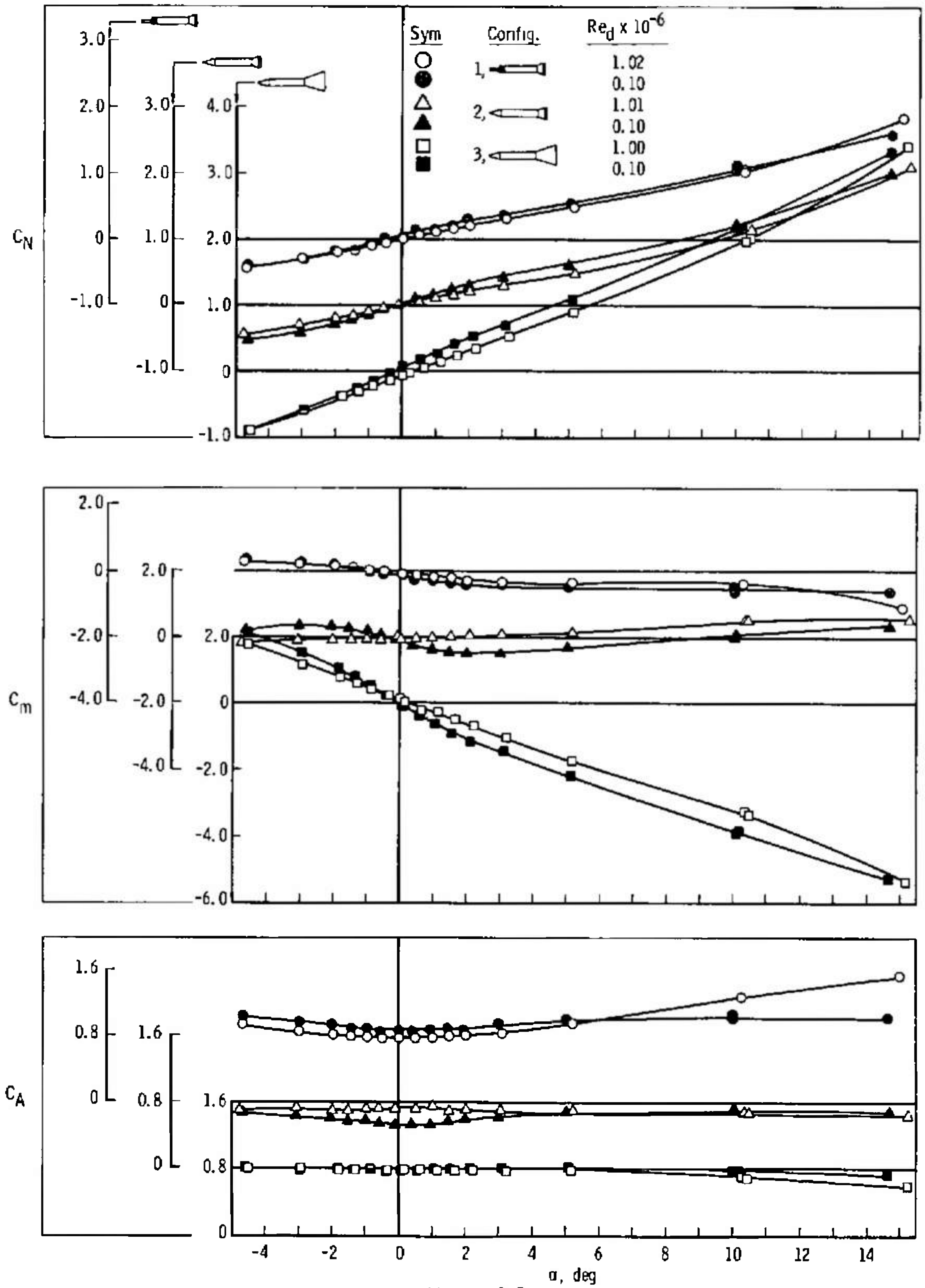
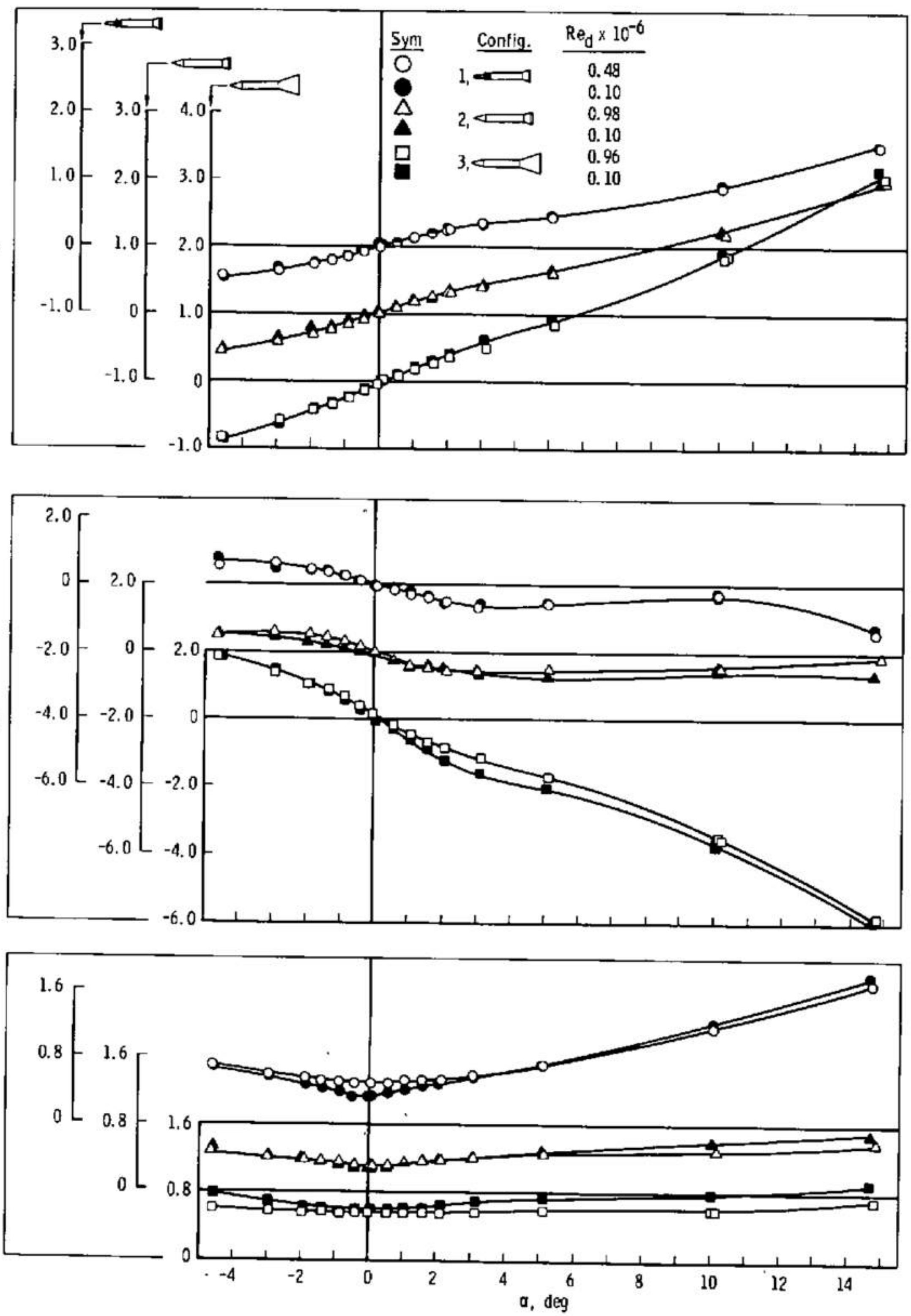


Fig. 2 Configuration 3 Installed in Tunnel A



a. M_∞ = 2.5

Fig. 3 Effect of Reynolds Number on Longitudinal Static Stability and Axial Force



b. $M_\infty = 5.0$

Fig. 3 Concluded

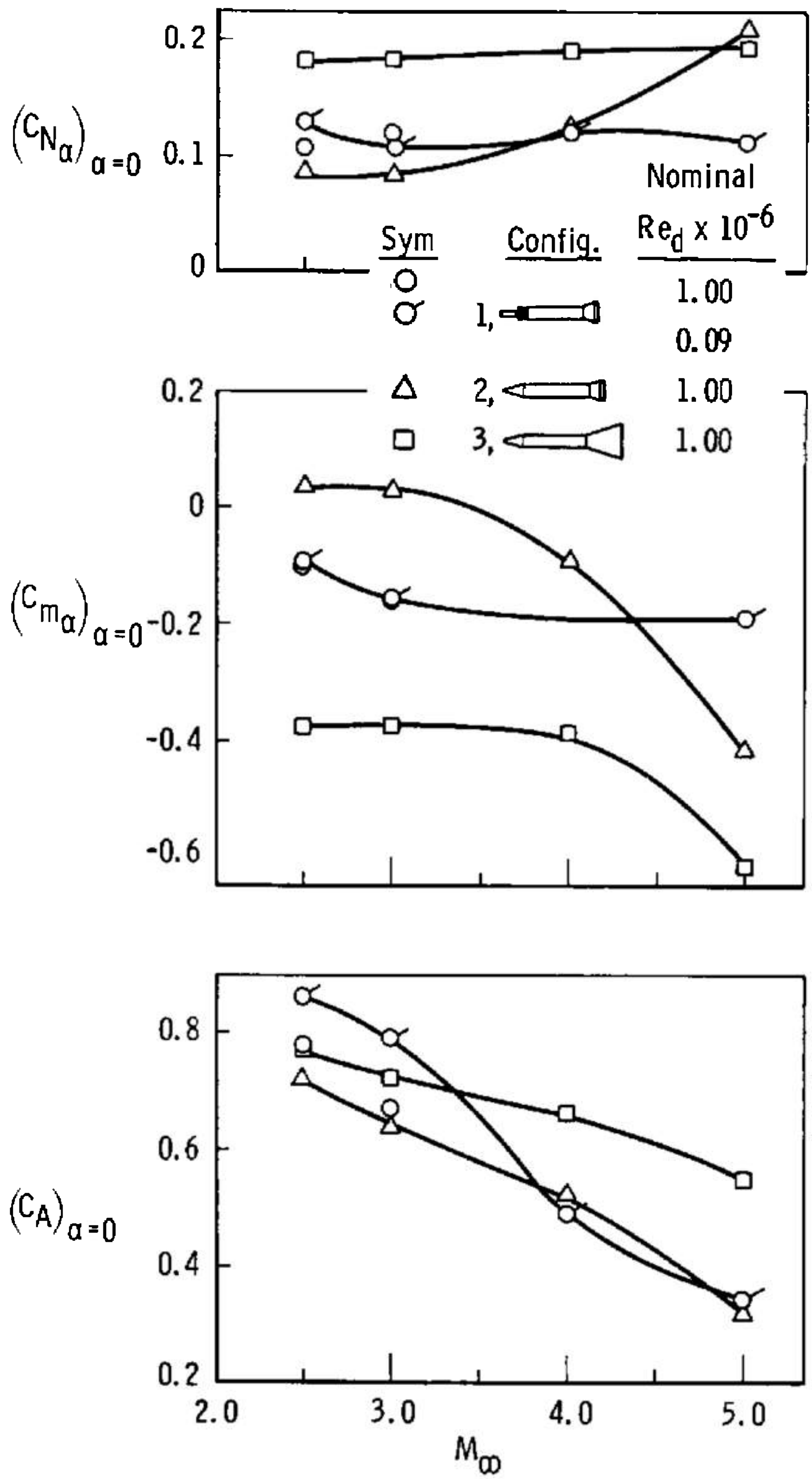
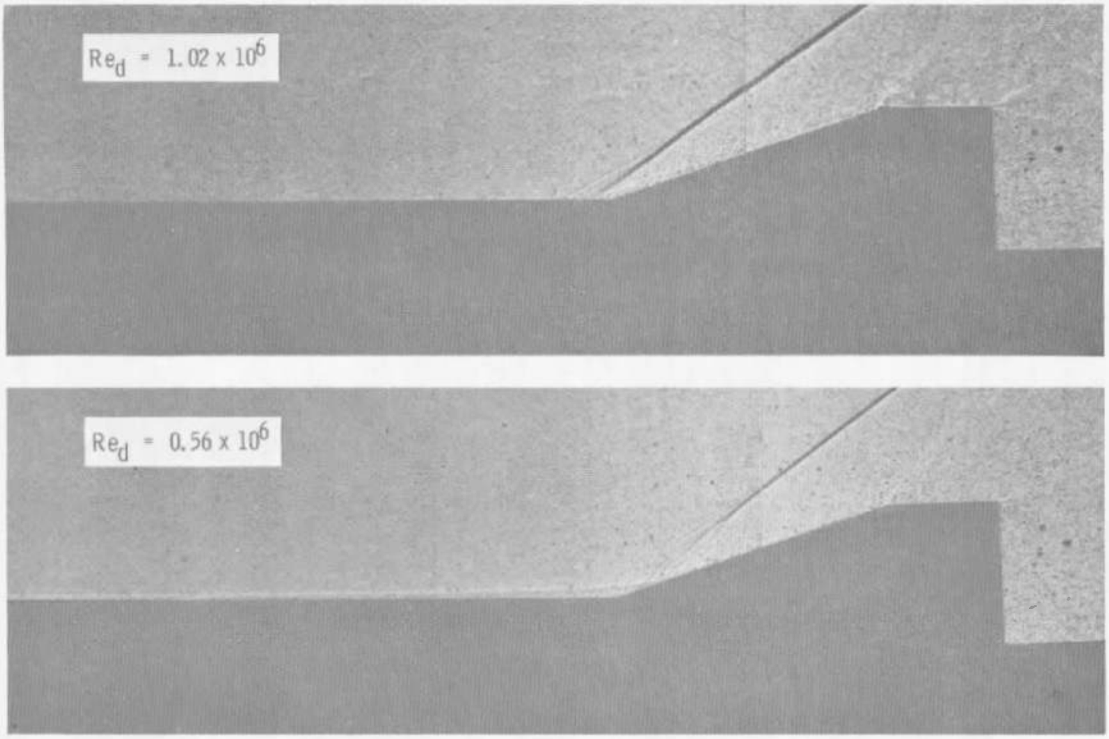
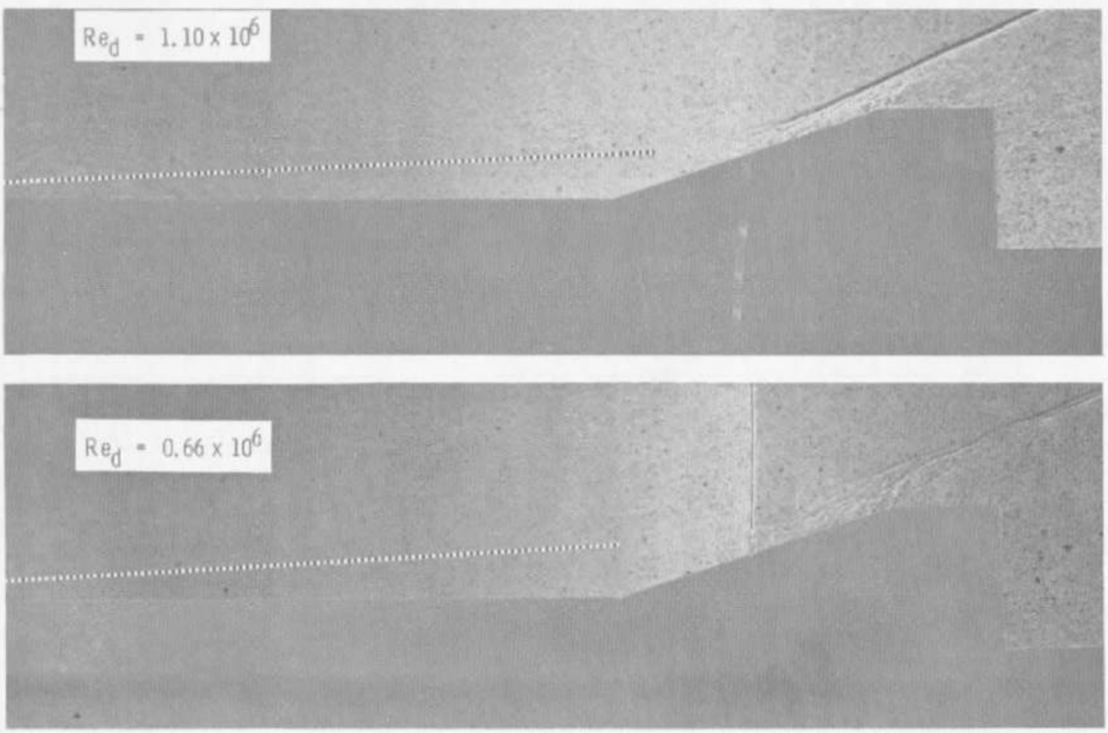


Fig. 4 Effect of Mach Number on C_{N_α}, C_{m_α}, and $C_{A_{\alpha=0}}$



a. $M_\infty = 2.5$



b. $M_\infty = 5.0$

Fig. 5 Typical Shadowgraphs, Configuration 2

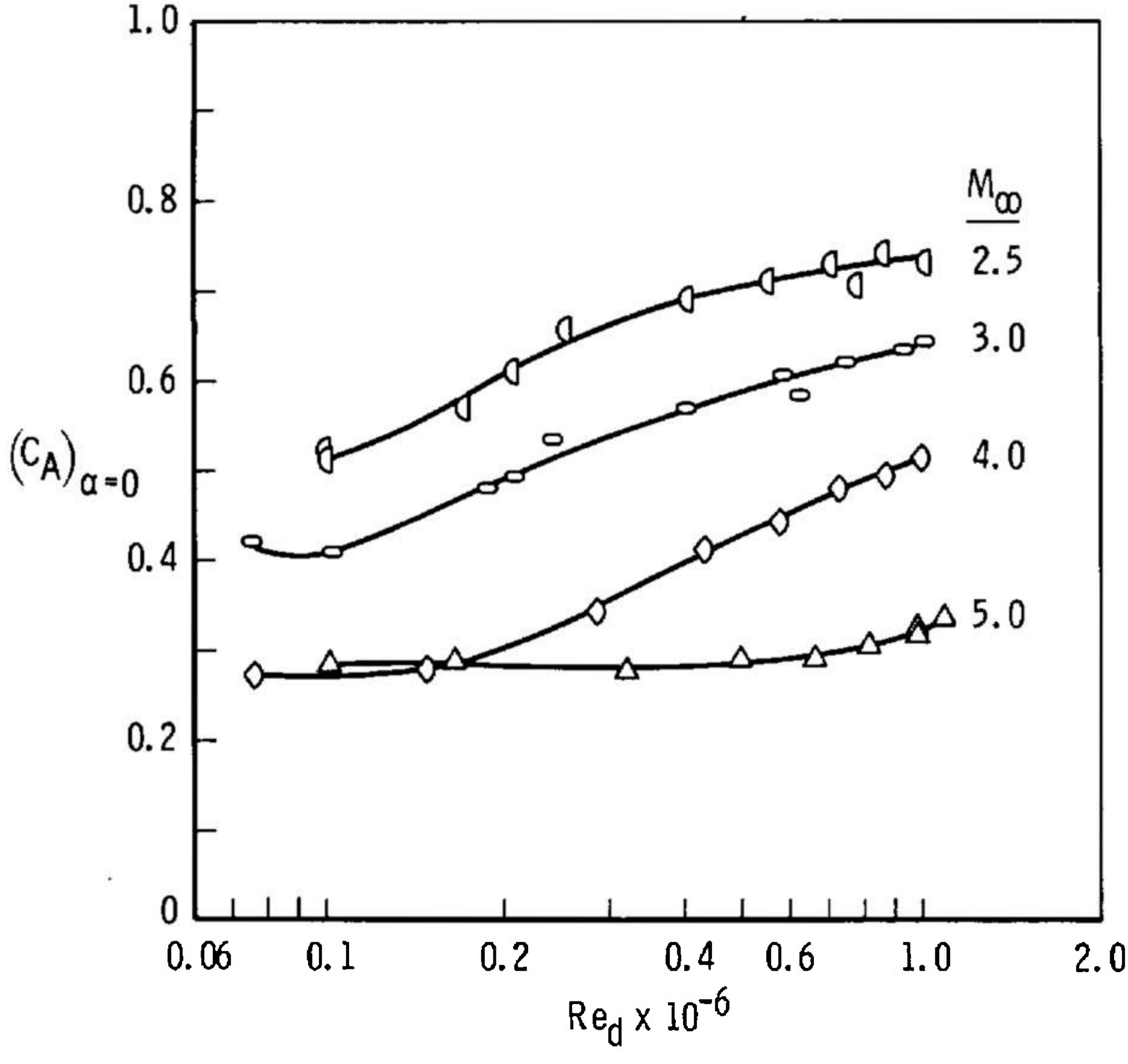
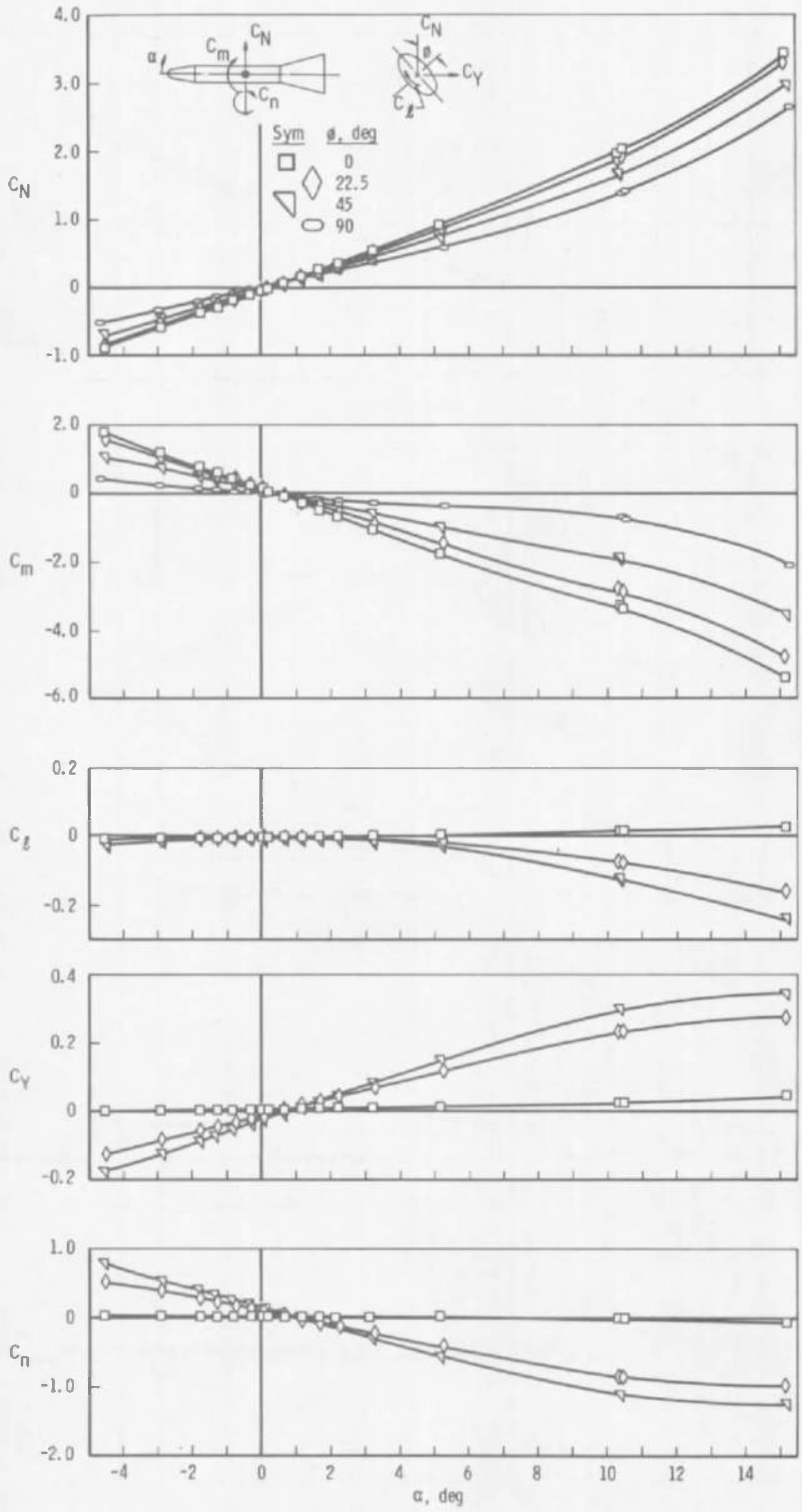


Fig. 6 Variation with Reynolds Number of the Zero-Lift Axial Force, Configuration 2



a. $M_\infty = 2.5$, $Re_d = 1.0 \times 10^6$

Fig. 7 Static Stability and Axial-Force Characteristics, Configuration 3

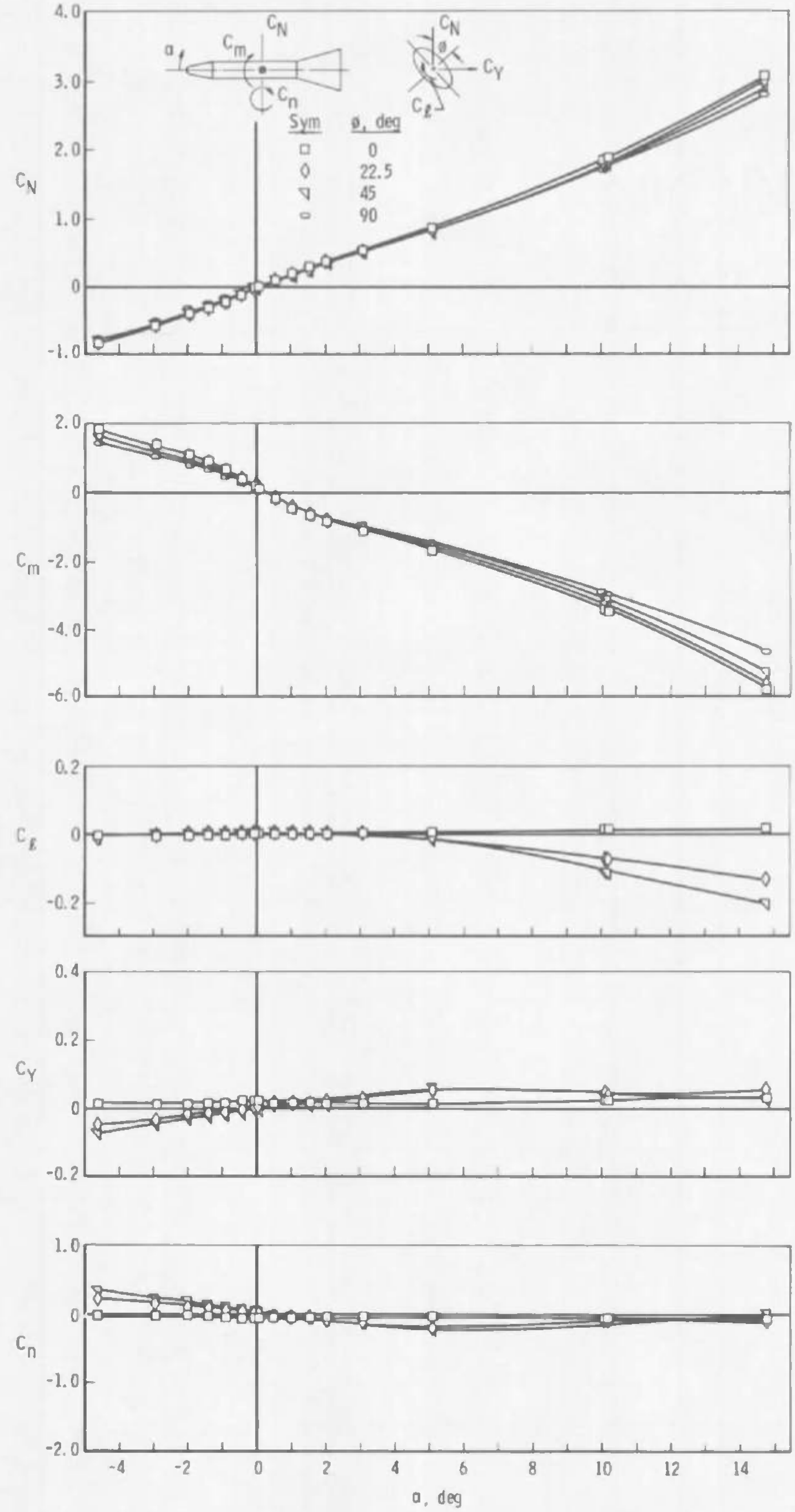


Fig. 7 Concluded
b. $M_\infty = 5.0$, $Re_d = 1.0 \times 10^6$

APPENDIX II
TABLE

TABLE I
TEST SUMMARY

Configuration	Nominal Mach Number	Calibrated Mach Number	α, deg	φ, deg	p_o, psia	T_o, °F	$Re_d \times 10^{-6}$
1	2.5	2.49	-5→15	0	3.0	105	0.096
		2.49			18.5	114	0.590
		2.50			33.8	120	1.026
	3.0	2.98			3.3	118	0.078
		2.99			25.4	121	0.596
		3.00			44.0	123	1.018
	4.0	3.98			5.8	119	0.080
		4.02			30.8	126	0.414
		4.02			58.0	94	0.850
	5.0	5.04			12.5	127	0.102
		5.03			20.7	120	0.174
		5.06			59.1	126	0.480
2	2.5	2.49			3.2	116	0.100
		2.50			20.8	114	0.640
		2.50			33.4	119	1.018
	3.0	2.98			3.2	118	0.076
		2.98			9.0	122	0.208
		2.99			26.8	123	0.624
		3.00			43.5	120	1.016
	4.0	3.98			5.3	111	0.076
		4.02			69.4	100	1.002
	5.0	5.02			12.3	122	0.102
		5.06			118.9	120	0.980
3	2.5	2.49		0, 22.5, 45, 90	3.1	92	0.100
		2.50			33.6	118	1.024
	3.0	2.98			3.1	120	0.072
		3.00			43.7	123	1.010
	4.0	3.98			5.3	117	0.074
		4.02			70.2	102	1.008
	5.0	5.02			12.4	120	0.102
		5.06			119.5	126	0.970

Note: Several intermediate Reynolds numbers were obtained for configuration 2, $\alpha = 0$.

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13 ABSTRACT

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static stability tests						
drag measurements						
wind tunnel testing						
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